FINAL REPORT

FOR

AN/GMD RAWIN SET RECEIVER SYSTEM

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

DECEMBER 1966

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

N67 18038 (ACCESSION NUMBER)	(THRU)
37 (PAGES)	1 (CODE)
CR 81628 (NASA CR OR TMX OR AD NUMBER)	07 (CATEGORY)

FACILITY FORM 602

BROWN ENGINEERING COMPANY, INC.

HUNTSVILLE, ALABAMA

CONTRACT NO. NAS8-20587

FINAL REPORT

AN/GMD RAWIN SET RECEIVER SYSTEM

By

Brown Engineering Company, Inc.
Huntsville, Alabama

ABSTRACT

This final report on the AN/GMD Rawin Set Receiver Systems study and the Solid State Receiver Subsystem development has been prepared for MSFC by Brown Engineering Company, Inc., under contract No. NAS8-20587.

The report describes the results of the range improvement study and the hardware design and development for the receiver subsystem.

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I. RANGE IMPROVEMENT STUDY

1.0 Purpose of Study

The purpose of the study is to evaluate techniques for range improvement of the AN/GMD Rawin System (Figure 1).

A number of approaches which provide similar performance parameters will be investigated from the standpoint of cost, reliability, size, weight, and environmental aspects.

1.1 Description of Equipment

The AN/GMD-2 Rawin Set includes a main assembly consisting of an antenna, an antenna pedastal, an antenna control, a 1660- to 1700-MHz receiver, a 400- to 406-MHz command transmitter, a comparator unit, and necessary interconnecting cables and accessories. The GMD has a form of conical scan detection system operating at a center frequency of 1680 MHz with a rotating or nutating cup for antenna pattern displacement. Tracking of the radiosonde is accomplished from the derived error signal caused by this pattern displacement. The receiver system consists of a single diode convertor followed by a vacuum tube 30-MHz intermediate frequency channel. The intermediate frequency channel has the additional circuitry necessary to demodulate the signal from the radiosonde set which contains the meterological and reference data for recording and interpretation.

2.0 Discussion

2.1 Rawin Receiver (R301 E)

The receiver, its associated mixer, and cables receive the 1600- to 1700-MHz (L-band) signal from the parabolic antenna (AS1117). The signal is mixed with the local oscillator signal in the mixer and

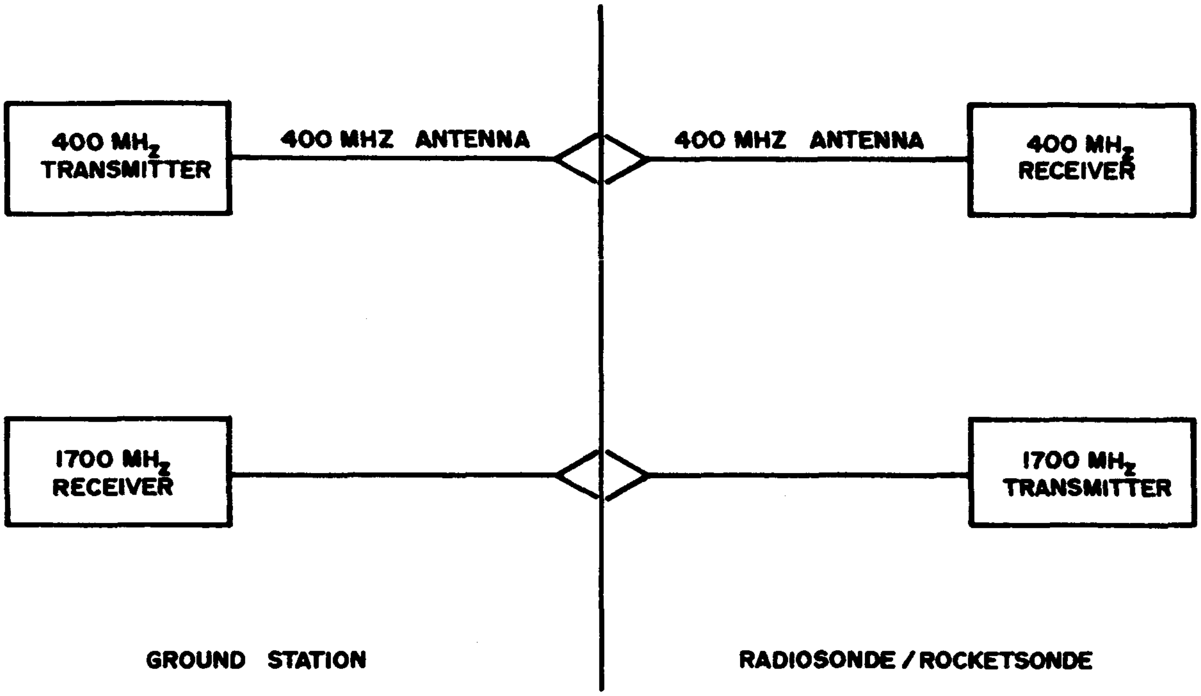


Figure 1. Simplified Block Diagram of AN/GMD-2 System RF Links

is converted to a 30-MHz IF signal. The 30-MHz IF signal is then amplified and demodulated. The existing noise figure of this receiver is about 15 db. For a reasonable value of antenna noise temperature, say 250°K, the receiver sensitivity is about -159 dbm per cycle.

Figure 2 shows a family of curves developed by Brown Engineering for the evaluation of receiver systems. The plot shows the system sensitivity (in decibels below one milliwatt per cycle of noise bandwidth) as a function of receiver noise figure expressed in decibels.

2.1.1 Single Diode Mixer

With the single diode convertor, both noise and local oscillator radiation problems result. To significantly improve the noise figure, and thus the sensitivity, and to decrease the local oscillator radiation, an RF preamplifier was deemed necessary. Two possible approaches were investigated.

(1) A non-degenerate parametric amplifier preceding the single ended mixer.

(2) A tunnel diode amplifier for preamplification and a balanced mixer preamplifier to replace the single ended mixer.

The total noise temperature of the system is the sum of antenna noise temperature and receiver noise temperature.

$$T_{SYS} = T_A + T_{REC}$$

where

T_{SYS} = System Noise Temperature

T_A = Antenna Noise Temperature

T_{REC} = Receiver Noise Temperature.

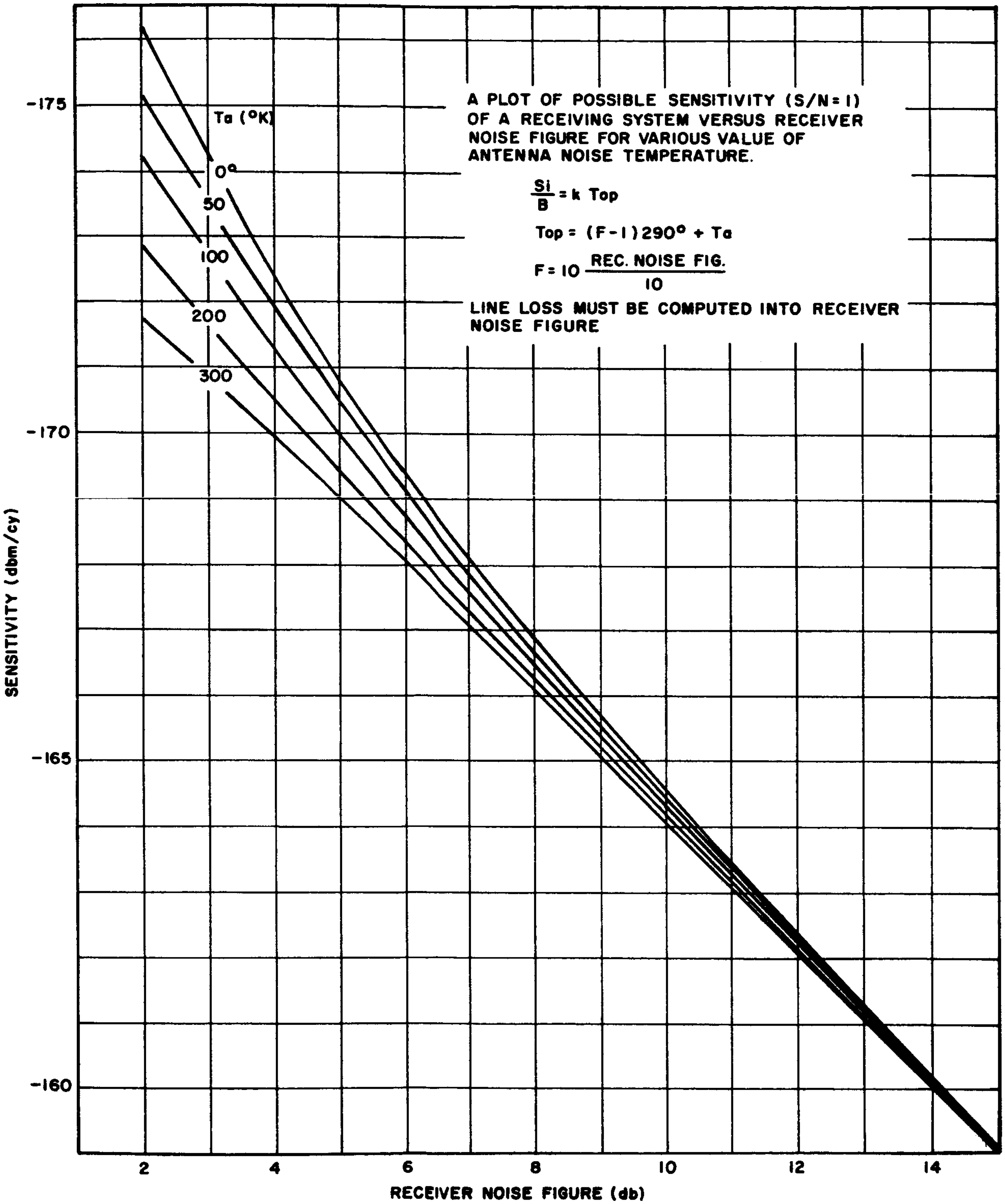


Figure 2. System Sensitivity Curves

The receiver noise temperature is given by:

$$T_{REC} = (F_1 - 1)\,290 + \frac{(F_2 - 1)\,(290)}{G1}$$

where

F_1 = First Stage Noise Figure

G_1 = First Stage Gain

F_2 = Second Stage Noise Figure.

For a parametric amplifier with $F_1 = 2.5$ db = 1.78:1 and a $G_1 = 15$ db = 31.6:1 installed preceding the existing single diode mixer with $F_2 = 15$ db = 31.61, the receiver noise temperature will be:

$$T_{REC} = (1.78 - 1)\;290 + \frac{(31.61\;-1)\;(290)}{31.61}$$

$$= 226 + \frac{8877}{31.61}$$

$$T_{REC} = 507°K.$$

For the antenna system with coaxial feed and the rotating cup, an antenna noise temperature of about 250°K is reasonable. The total system noise temperature is then:

$$T_{SYS} = 250°K + 507°K$$

$$T_{SYS} = 757°K.$$

If the existing single diode mixer is replaced with a balanced mixer-preamplifier and a tunnel diode amplifier with image rejection filtering (Figure 3), then noise performance will be as follows: assuming $F_1 = 4.5$ db = 2.82:1, $G_1 = 15$ db = 31.61:1, and

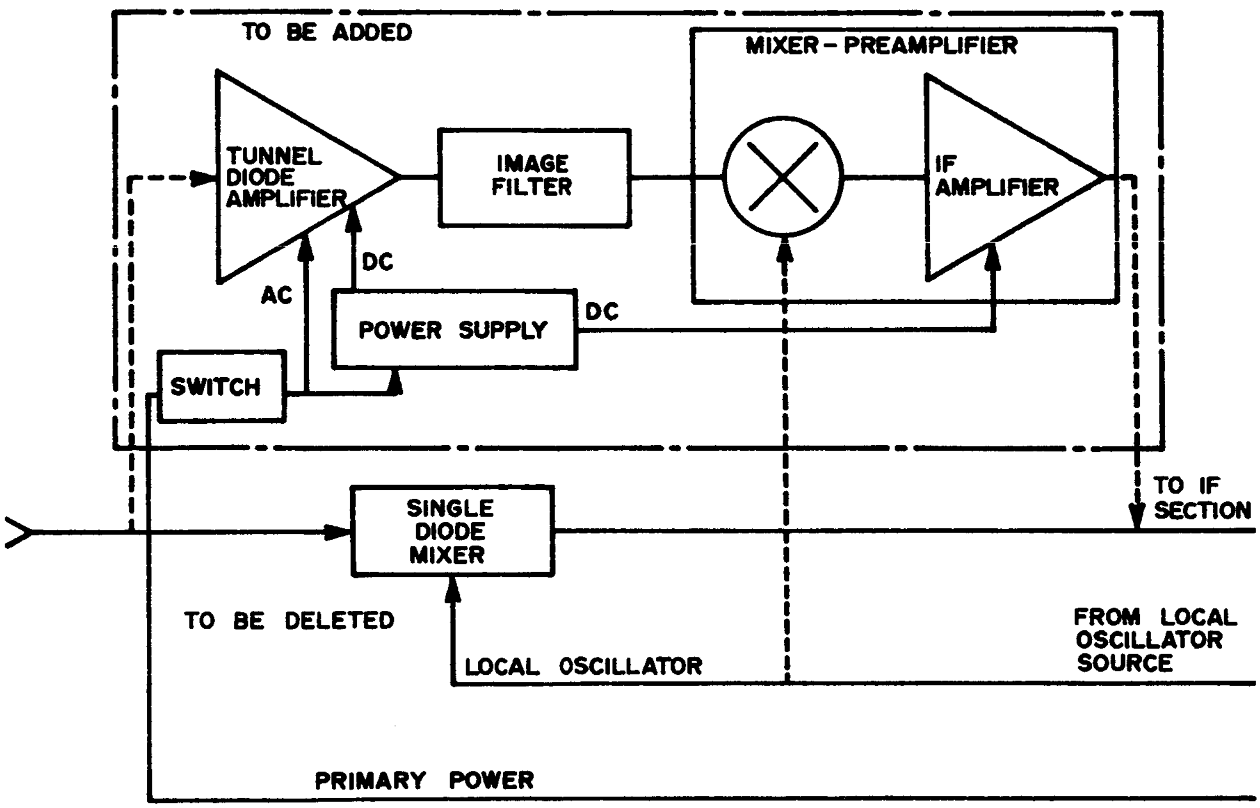


Figure 3. Block Diagram of AN/GMD Receiver Improvement Changes

F_2 = 5 db = 3.16:1 (no image response), the receiver noise temperature will be:

$$T_{REC} = (2.82 - 1)\,290 + \frac{(3.16 - 1)\,290}{31.61}$$

$$= 529 + \frac{626}{31.61}$$

$$T_{REC} = 547°K.$$

By adding 250°K for antenna noise temperature, the system noise temperature is

$$T_{SYS} = 250°K + 547°K$$

$$T_{SYS} = 797°K.$$

Noise power input to the system is given by:

$$P_n = KTB_{eq}$$

where

P_n = System Noise Power Input

K = Boltzman's Constant

B_{eq} = Equivalent Systems Noise Bandwidth.

It is seen that about a 0.5-db better signal-to-noise ratio is achieved with the parametric amplifier over the tunnel diode amplifier, filtering and mixer preamplifier system. This difference in performance is very small and would not be detectable using normal techniques.

The above relationships have not considered the noise input to the system caused by noise generated in the local oscillator. In a single diode mixer there is no provision for eliminating this noise. Noise generated by the local oscillator will be amplified and coupled into the output of the IF amplifier along with the desired signal. On the other hand, local oscillator noise is cancelled in the balanced mixer due to the phase relationships existing in the hydrid that couples the diodes to the signal and local oscillator.

The tunnel diode amplifier with the balanced mixer preamplifier and image filtering also provides greater than 60 db of local oscillator rejection enabling operation of adjacent receiving systems without interference from local oscillator radiation.

The parametric amplifier approach appeared to be very expensive for the amount of improvement provided by it, and also posed some system interface problems not presented by the tunnel diode amplifier system.

Aside from the cost factor, the tunnel diode amplifier was chosen over the parametric amplifier for the following reasons:

(1) The unit provided is a complete system and not just a component. It provides improvements other than noise figure (i. e., local oscillator rejection and image filtering).

(2) The complete system in its 8- by 10- by 3-inch housing could be mounted directly behind the parabolic antenna, near the center of rotation, with a minimum amount of RF cable length and the resulting loss that is attendent with long RF cable runs. The added weight is less than 12 pounds and will not affect the mechanical operation of the tracking unit.

(3) No cable revisions required over present system.

(4) Low power drain (115 vac, 1/4 amp).

(5) Reliability in the all solid state subsystem provides considerable reliability advantage over the parametric amplifier with its pump.

(6) No tuning is required. After installation, no gain, frequency, or phase adjustments are required.

The modified receiver reduces the noise figure below 6 db. Plotting 6-db receiver noise figure and 250°K antenna noise temperature, a -168 dbm per cycle sensitivity is noted, and the resulting improvement is about 9 db.

To evaluate the range improvement which is gained from this sensitivity improvement, the Radar Beacon Equation can be used. The Radar Beacon Equation is given by the following relationship:

$$\frac{P_R}{P_T} = \frac{G_T G_R \lambda^2}{16\pi^2 R^2}$$

where

P_T = Power Transmitted from Beacon (Radiosonde)

G_T = Transmitter Antenna Gain

G_R = Receiver Antenna Gain

λ^2 = RF Wavelength Squared

P_R = Received Power

P_{R_1} = Minimum Receivable Power (old system)

P_{R_2} = Minimum Receivable Power (new system).

For purposes discussed here, the power transmitted $\left(P_T\right)$, the antenna gains $\left(G_T \text{ and } G_R\right)$, and the wavelength ($\lambda^2$) can be regarded as constants since the receiver modification does not change any of these parameters. The 9-db improvement converts to a ratio of 8:1. This ratio injected in the Beacon equation shows a net range improvement of the square root of 8 or 2.83 times previous range capability.

The expression for receiver noise figure is given by the following relationship:

$$F_R = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_2} \qquad (1)$$

where

F_R = Receiver Noise Figure

F_1 = First Stage Noise Figure

G_1 = First Stage Gain

F_2 = Second Stage Noise Figure

G_2 = Second Stage Gain

F_3 = Third Stage Noise Figure.

The modified system has the following values for these parameters:

F_1 = 4.5 db = 2.82:1

G_1 = 15 db = 31.6:1

F_2 = 8.0 db = 6.4:1

G_2 = 18 db = 46.1:1

F_3 = 4 db = 2.51:1.

Injecting these figures into Equation (1) yields a receiver noise figure of about 3.0 or 5 db.

2.1.2 IF Amplifier and Demodulator

The IF amplifier, in the receiver, is a vacuum tube amplifier operating at 30 MHz. There are four demodulators associated with the IF amplifier. These are:

(1) A broad A.M. detector, the output of which contains the meteorlogical information and the 34-Hz conical scan information.

(2) A broad F.M. detector which demodulates the 81-KHz ranging information.

(3) A sharp A.M. detector.

(4) A sharp F.M. detector.

The sharp detectors demodulate the same signals as the broad detectors; however, the bandwidth has been sharpened to 0.8 MHz compared to the 2.5-MHz bandwidth of the first five amplifier stages.

Investigations of the IF strip indicated stable operation of the first five amplifier stages under laboratory conditions. No detuning of the IF amplifier bandpass characteristic was observed after extended periods of operation nor when removed from receiver chassis and reinserted. Investigations have indicated, however, that improvements could be made to the broad F.M. detector, sharp F.M. demodulator, and the local oscillator.

The broad F.M. detector is actually a phase detector with a self-contained reference oscillator. If the reference oscillator frequency drifts, the demodulator characteristic will change causing erratic ranging signals. The sharp F.M. detector is a Foster-Seeley discriminator, the dc output of which is also used as an AFC error signal. Improper alignment of the discriminator will produce a serious stability problem in the receiver.

The following modifications of the receiver are recommended:

(1) Replace the present AFC circuit with a circuit similar to the one shown in Figure 4. Provision should be made for AFC disable and a voltage tuning control which would be compatible with the present receiver tuning dial.

(2) Replace the present local oscillator with a voltage controlled transistor unit. This unit to be incorporated in the tunnel diode subassembly housing, thus eliminating the cable from the receiver panel to the subassembly and the potential RFI problem.

(3) Replace the present receiver with a solid state receiver. In the interest of improved performance and reliability and a reduction in size and weight, an all solid state version of the R301 receiver should be considered. A preliminary design (Figure 5) has been formulated offering improvements in sensitivity, stability, spurious response characteristics, and in dynamic range.

Modifications 1 and 2 would greatly improve the L-band receiver stability and reliability and will significantly reduce the weight of the receiver.

2.1.3 Saturation and Dynamic Range

Investigation of the 1680-MHz down link operation have shown that during launch and calibration procedures the receiving system with the added gain and lower saturation level afforded by the receiver subsystem will be at or near a saturation condition.

This information is based on the assumption of maximum RF power output from the radiosonde (0.5 watt) and an antenna gain of 29 db. The antenna is also assumed to be at a sufficient distance from the radiosonde such that uniform illumination of the antenna operature

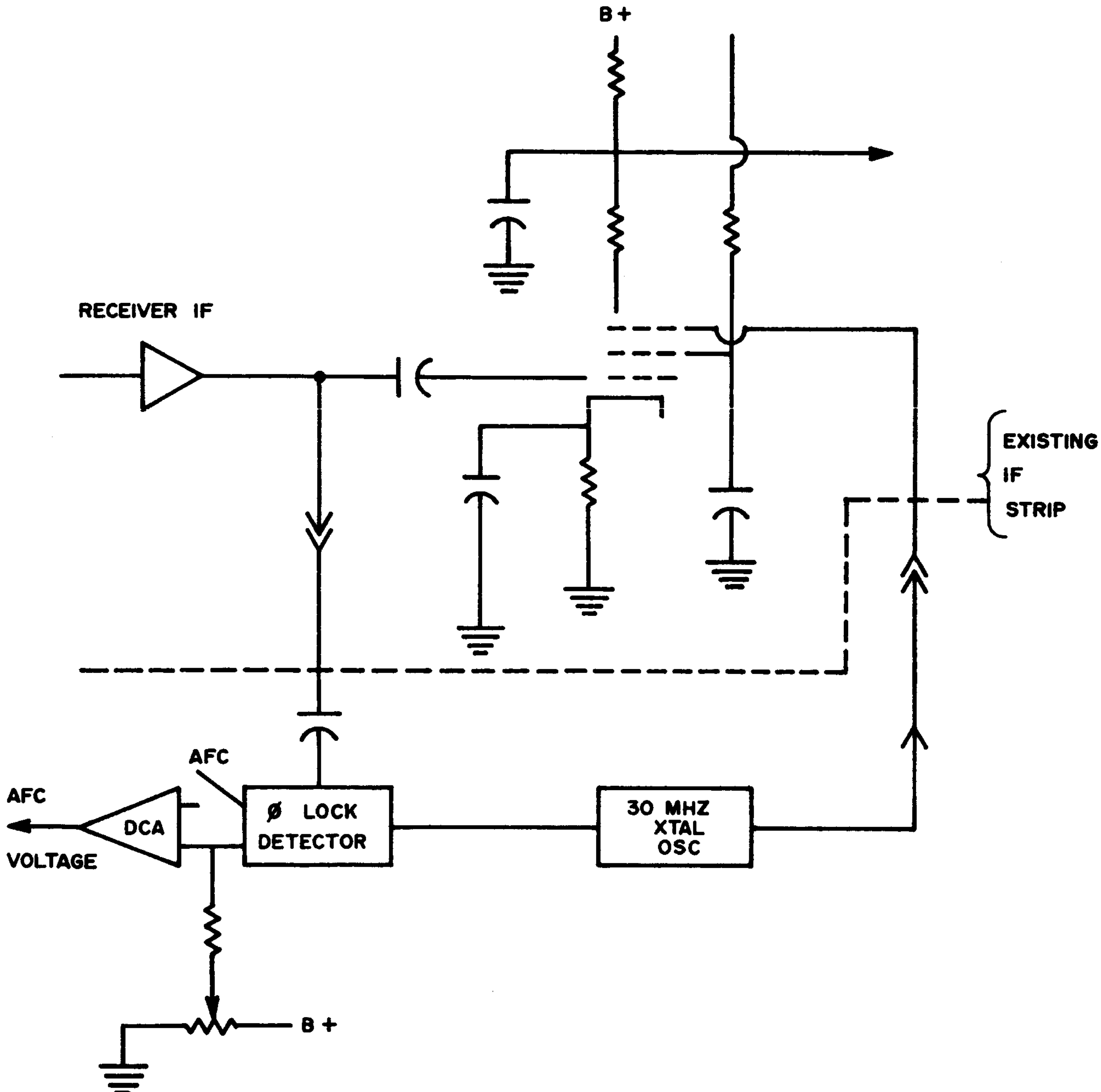


Figure 4. AFC Replacement Circuit

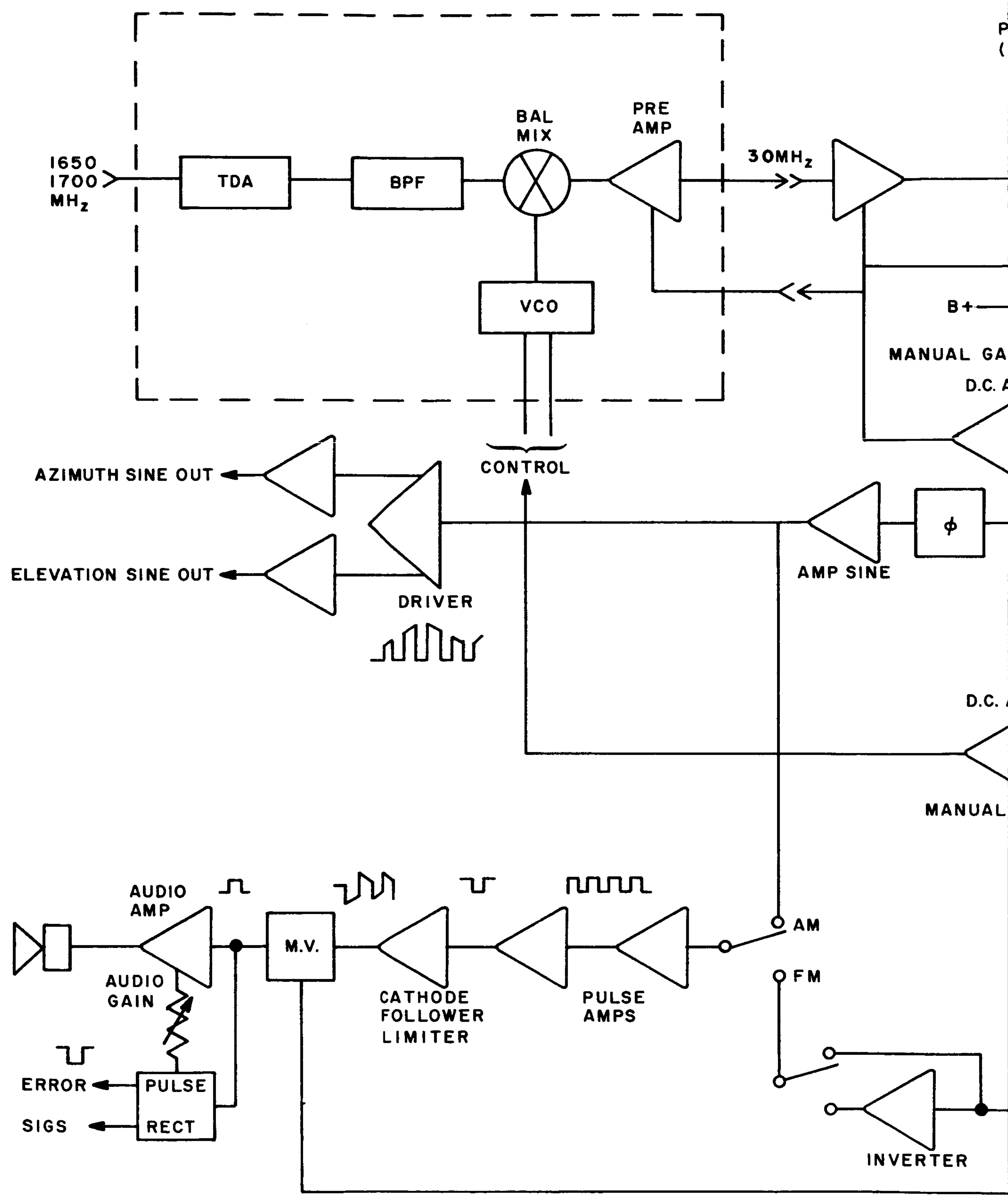
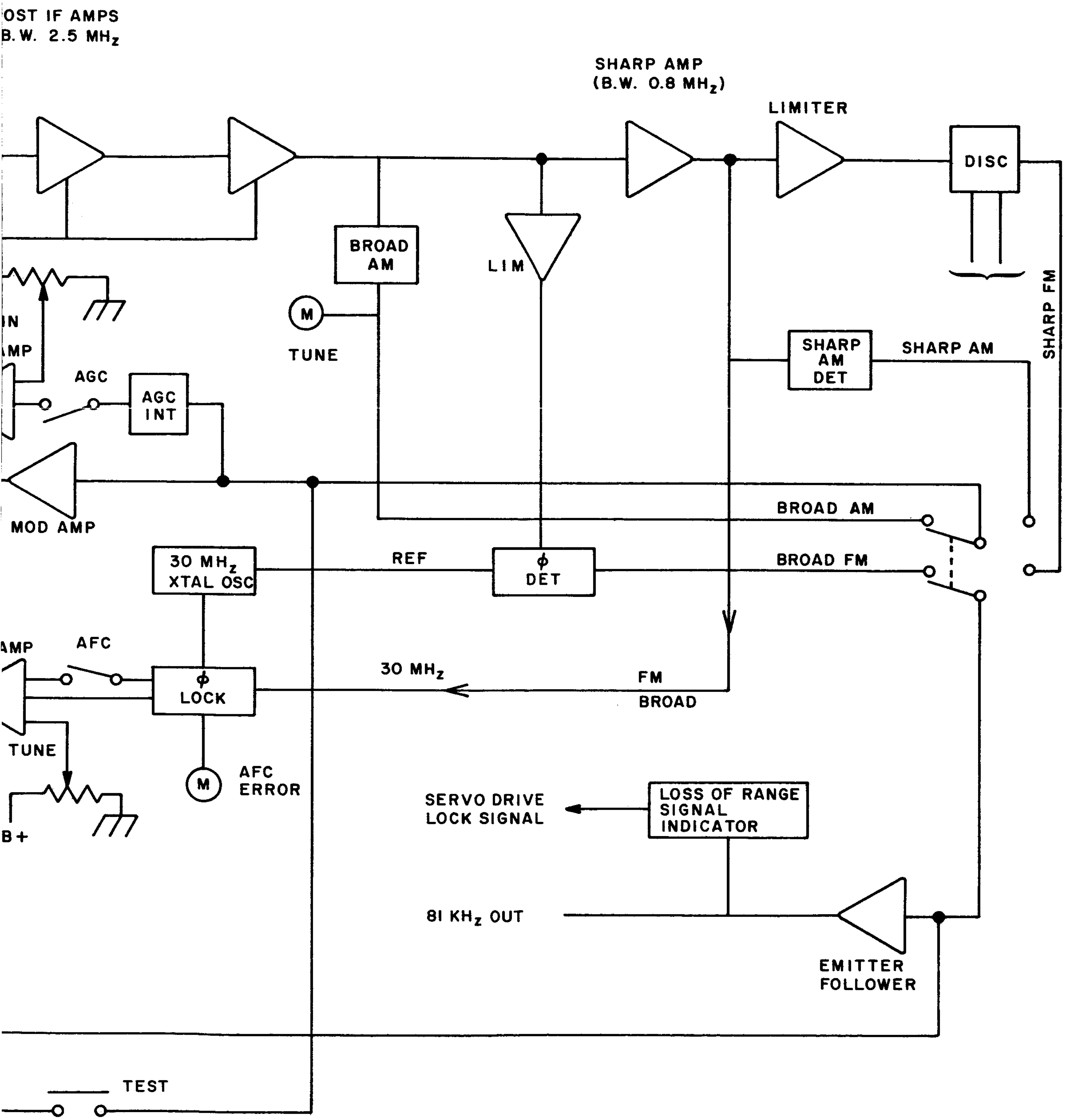


Figure 5. Preliminary Receiver Block Diagram 14-1


OST IF AMPS
B.W. 2.5 MHz
SHARP AMP
(B.W. 0.8 MHz)
LIMITER
DISC
BROAD AM
LIM
M
TUNE
SHARP FM
SHARP AM DET
SHARP AM
IN
AMP
AGC
AGC INT
MOD AMP
BROAD AM
BROAD FM
30 MHz XTAL OSC
REF
φ DET
AMP
AFC
φ LOCK
30 MHz
FM
BROAD
TUNE
M
AFC ERROR
B+
SERVO DRIVE LOCK SIGNAL
LOSS OF RANGE SIGNAL INDICATOR
81 KHz OUT
EMITTER FOLLOWER
TEST

occurs. The latter assumption holds well for the launch range but may not be valid for the calibration range.

This saturation condition could result in loss of the antenna position information contained in the 34-Hz AM modulation produced by the conical scan.

The actual RF power level at the receiver input was measured during a calibration procedure. The measured level of -30 dbm was considerably less than that calculated. However, the level is still sufficient to cause saturation of the receiving system. This problem has been circumvented in the past by slewing the antenna main beam off the direction of maximum radiation from the radiosonde.

It is suggested that this problem be corrected by utilizing the Fail Safe characteristic of a tunnel diode amplifier with a five-port circulator. Tunnel diode amplifiers, with five-port circulators, will pass an incoming signal with negligible attenuation of that signal in the event of diode failure. This condition may be simulated by merely removing the dc bias on the tunnel diode. This will result in a gain decrease of 18 db. The decrease in gain will bring the system out of saturation. The amplifier could be turned on again, when the added gain was needed, either manually or automatically (if the switch is controlled by the AGC signal).

2.2 Comparator (CM63)

The comparator is the data processing unit and has no direct function by which it can limit range performance. However, the range data reliability is directly related to this unit and to its input data.

2.3 Transmitter (T-456)

The transmitter has the function of providing a 403-MHz command signal to the radiosonde. The 403-MHz signal is plate modulated by the 81-KHz ranging signal. The radiosonde demodulates the 81-Hz signal and returns it to the ground station as an FM signal or, in the case of the lightweight sonde, a complex AM signal on the L-band carrier.

The transmitters, in good repair, normally have a RF power output of 15 watts. Modification or improvement of the transmitter does not appear necessary or economically desirable.

2.4 403-MHz Transmitter Antenna

As indicated previously, the receiver modification provides a beacon range increase of better than 150 percent due to the improved noise performance of the receiver. To assure this range improvement for the overall system, it will be necessary to ensure that the beacon range of the 403-MHz up link is consistent with the 150 percent improvement of the 1680-MHz radiosonde receiver. This can be ensured by increasing the 403-MHz transmitter power or by increasing the transmitting antenna gain. Inasmuch as the study was concentrated on the GMD system, the sonde improvement is not considered in the recommendation.

Increase in the 403-MHz transmitter power would be an expensive method of obtaining the additional range required. In view of this, it is recommended that a new 403-MHz antenna be designed for the system. This antenna would preferably be mounted on top of the parabolic reflector along the same boresight as the 1680-MHz dipole. The antenna could be either a helical or yagi type antenna of from 10 to 13 db gain. The helical antenna by virtue of its circular polorization would preclude the possibility of signal dropout due to cross poloriztion caused by the 403-MHz antenna on the radiosonde swinging like a pendulum. Either of these antennas wouldbe light weight, economical, and easily installed.

2.5 Receiving Antenna

The antenna is a parabolic reflector type with a dipole feed. It is used as a receiving antenna for the 1680-MHz radiosonde-to-ground link.

The antenna has a 28.1-inch focal length, 29-db directive gain, and a 6.5° half power beamwidth. The antenna receives vertically polarized signals.

It is felt that the 403-MHz transmitting antenna, in its present location, causes a certain amount of shadowing or distortion of the main beam of the 1680-MHz receiving antenna. This will result in some degradation of the aforementioned reflector parameters. For this reason and those mentioned in paragraph 2.4, it is recommended that the 403-MHz transmitter antenna be relocated and/or redesigned.

II. RECEIVER SUBSYSTEM DEVELOPMENT

3.0 Receiver Subsystem

The receiver subsystem is an all solid state unit housed in a 8- by 10- by 3-inch casting. Contained within the housing is a tunnel diode amplifier, a mixer preamplifier, an image rejection filter, and a bias power supply.

The overall system improvements provided by the receiver subsystem was 9 db in receiver sensitivity, 60 db of local oscillator rejection, and 25 db image rejection.

The RF-to-IF gain provides is 33.5 db, and the subsystem bandwidth is 7 MHz. Figure 6 is a plot of subsystem gain vs frequency.

The receiver subsystem noise figure is 5.5 db. Figure 7 illustrates the system linearity and saturation curve.

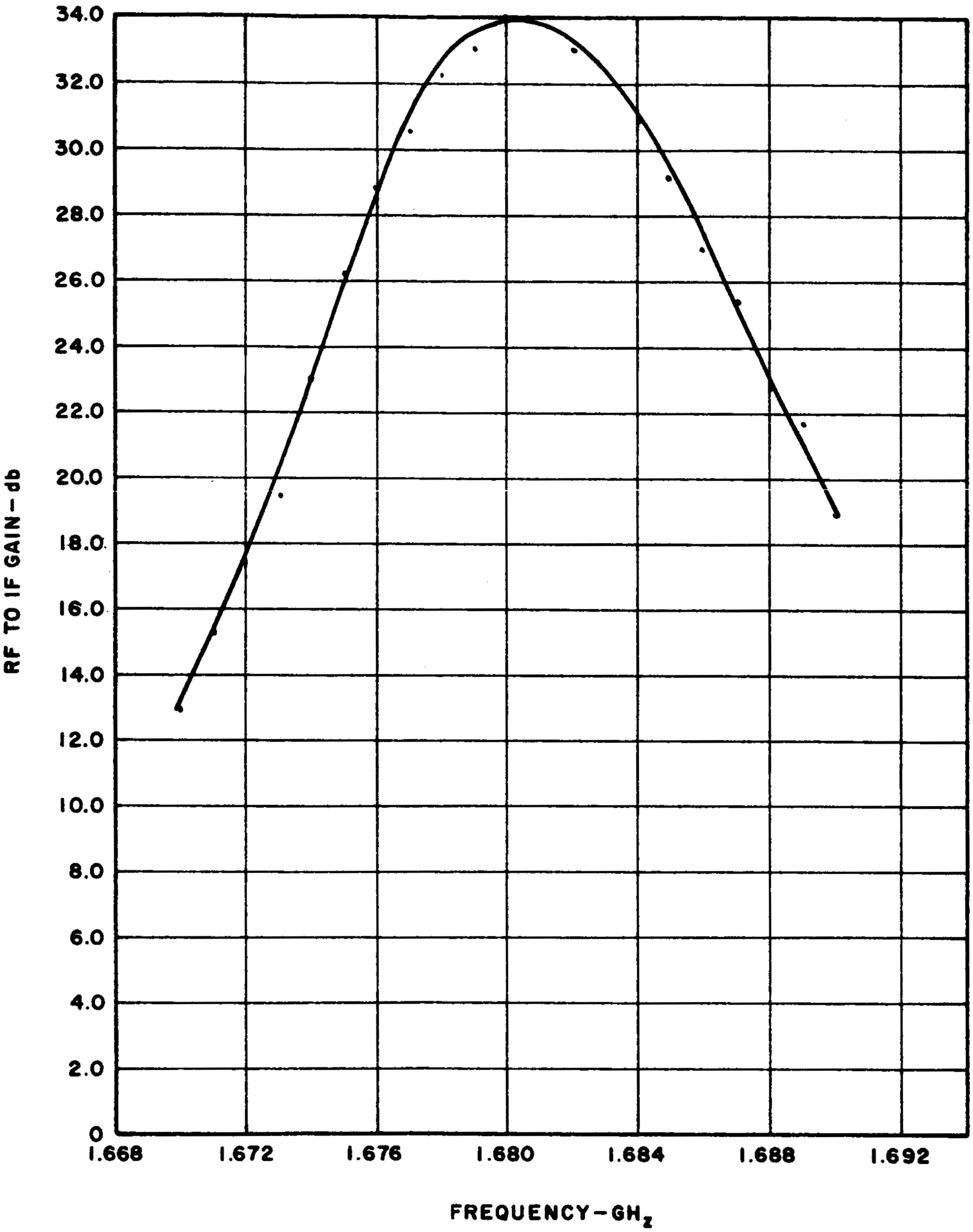


Figure 6. Receiver Subsystem RF Bandwidth Curve

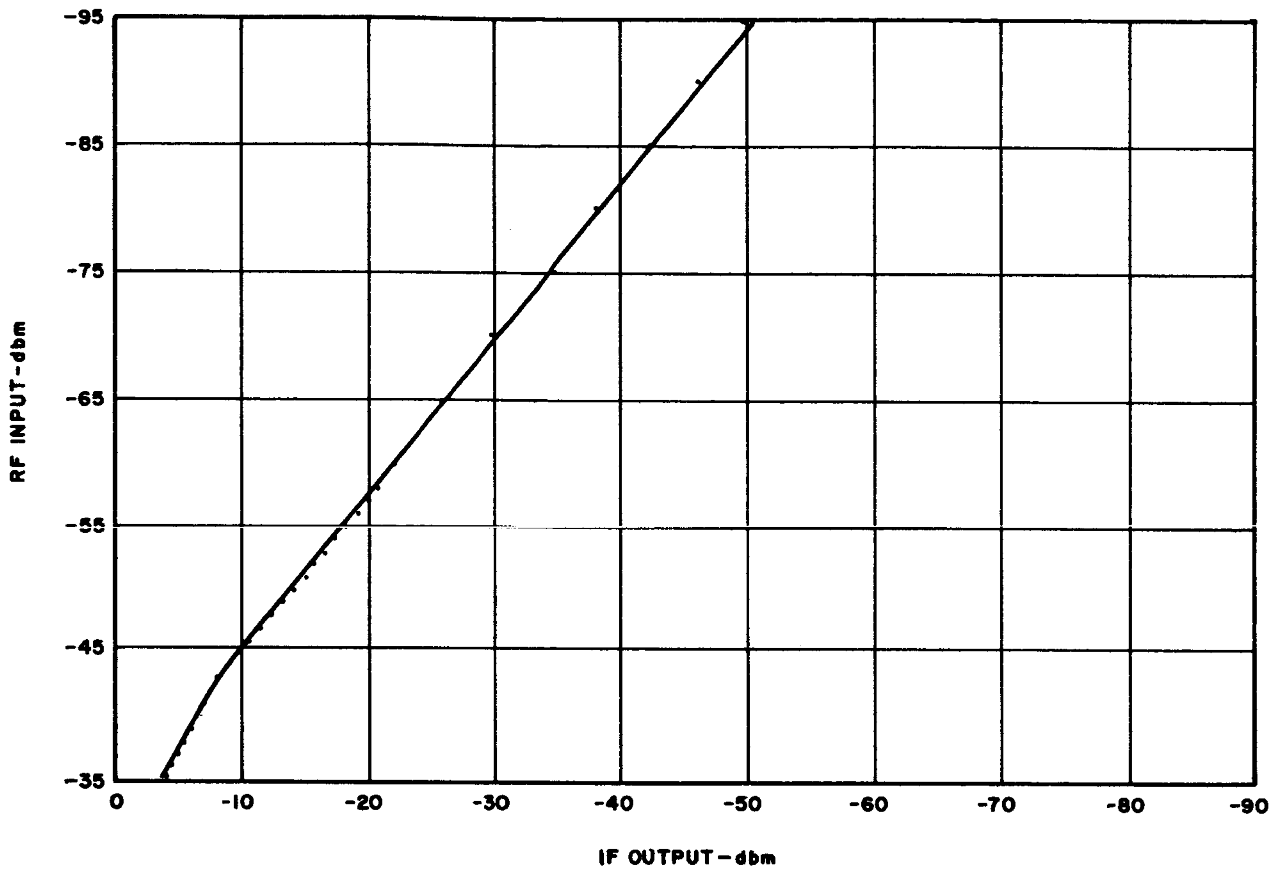


Figure 7. Receiver Subsystem Linearity Curve

3.1 Tunnel Diode Amplifier

The tunnel diode amplifier supplied within the receiver subsystem housing is a circulator coupled reflective type amplifier.

A five-port circulator is utilized as a coupling network for the tunnel diode to guarantee absolute stability and to provide a gain response that is very nearly independent of source and load impedance. An additional benefit is gained from the five-port circulator in that Fail Safe operation is attained. Should diode failure occur, which is highly unlikely, the incoming signal will pass through the amplifier unchanged except for the small insertion loss due to the circulator. See Appendix for test data sheet.

3.1.1 Dynamic Range

The dynamic range of the amplifier is determined, on the low end, by the noise level of the amplifier and on the high end by the saturation characteristics of the various components comprising the amplifier.

The lower limit of dynamic range is given as follows:

$$S(\text{dbm}) = -114 \text{ dbm} + 10 \text{ Log BW(MHz)} + F(\text{db})$$

$$S(\text{dbm}) = -114 \text{ dbm} + 10 \text{ Log } 2.5 + 4.5 \text{ db}$$

$$S(\text{dbm}) = -114 \text{ dbm} + 10\ (4.0 + 4.5) = -105.5 \text{ dbm}.$$

The upper limit of dynamic range is defined as the input power which causes the amplifier to deviate from linear amplification by 1.0 db. The measured value for this upper limit was -39 dbm (Figure 8). Test equipment limitations precluded measurements below -95 dbm.

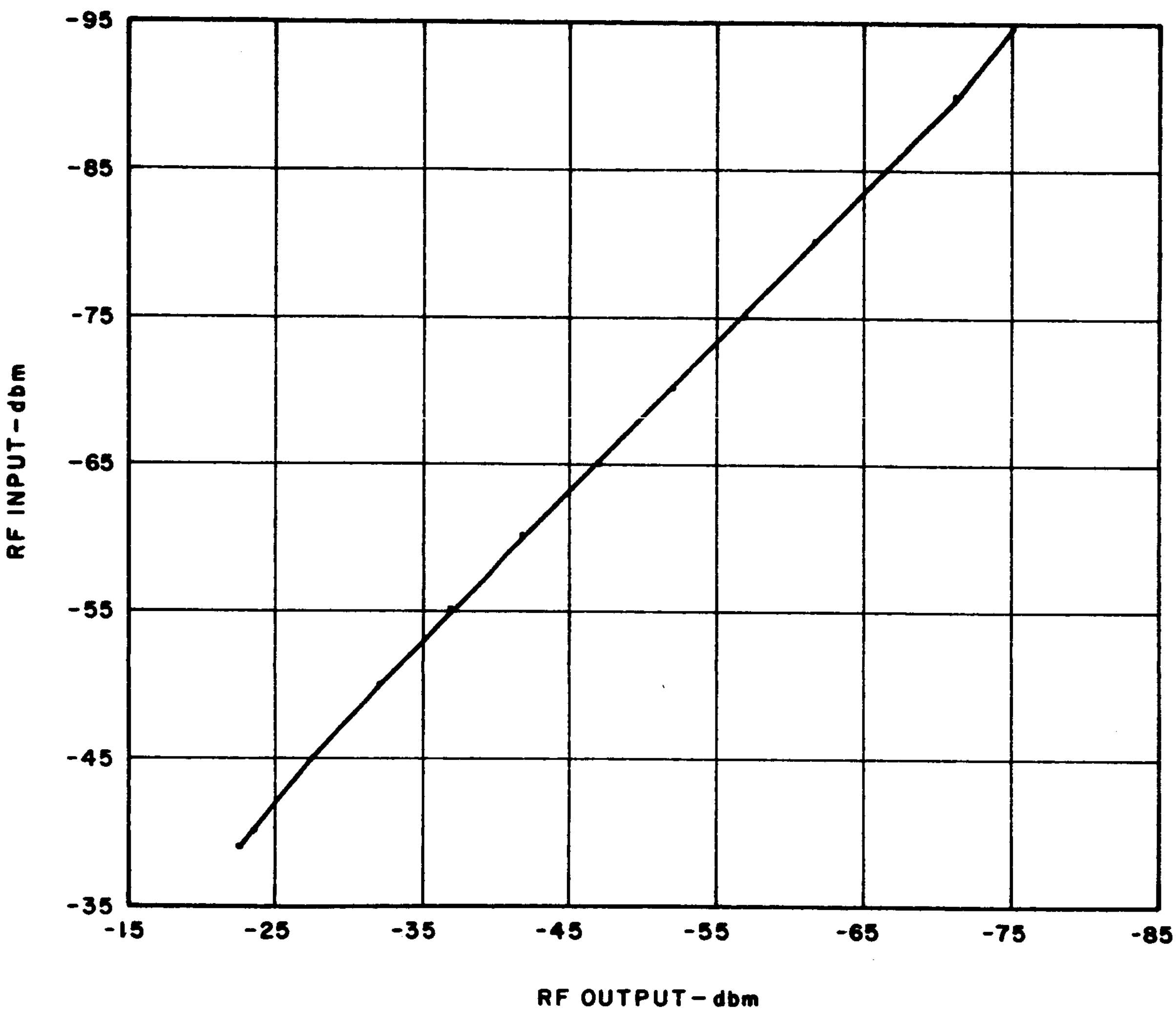


Figure 8. Tunnel Diode Amplifier Linearity Curve

3.1.2 Power Handling Capabilities

The tunnel diode amplifier will withstand average RF input power of 50 MW. Tolerable spike leakage levels are 0.1 erg (1-nanosecond pulse) and 0.2 erg (25-nanosecond pulse).

3.1.3 Frequency Bandwidth and Gain

The tunnel diode amplifier was designed to amplify at a center frequency of 1680 MHz. The gain at 1680 MHz was measured to be 17.0 db. At the points ±30 MHz away from the center frequency the gain was within +0.5 db. The 3-db bandwidth is 170 MHz. Figure 9B shows the swept frequency response of the amplifier.

3.1.4 Temperature

The tunnel diode amplifier has a heater unit that operates from 115 vac 60 Hz. The heater unit serves with the temperature compensating circuits to preserve the room temperature noise figure and gain characteristic (Figure 9ABC).

3.1.5 Noise Figure

The noise figure of the tunnel diode amplifier was measured to be 4.5 db at 1680 MHz.

3.2 Mixer Preamplifier Specifications and Tests

The mixer preamplifier is a combination balanced mixer and solid state IF amplifier. See Appendix for test data sheet

3.2.1 Linearity and Saturation

The mixer preamplifier provides mixing and linear amplification of RF inputs up to a level of -23 dbm, at which point saturation occurs. Figure 10 illustrates the saturation characteristic.

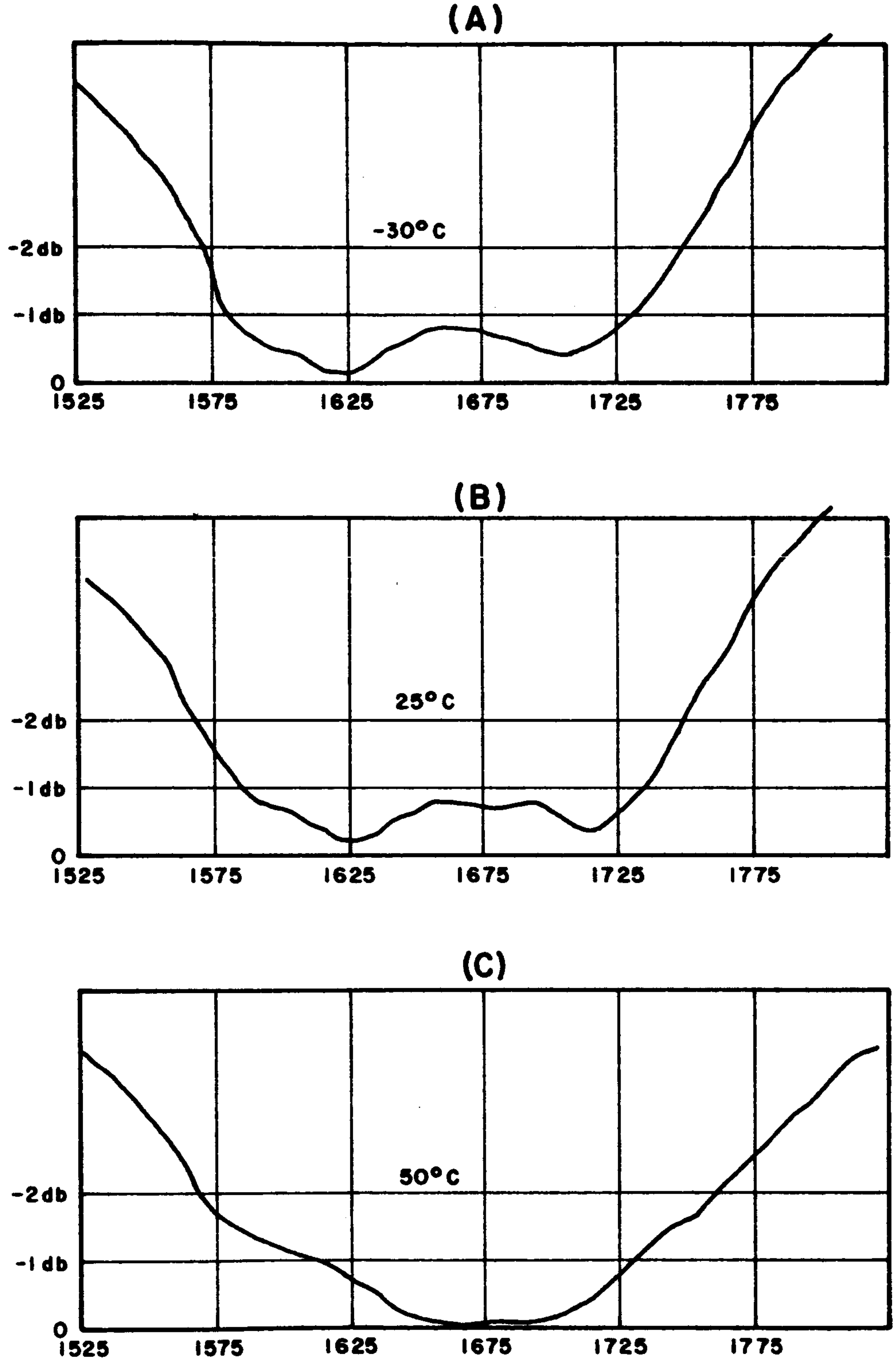


Figure 9. Tunnel Diode Amplifier Bandpass Display

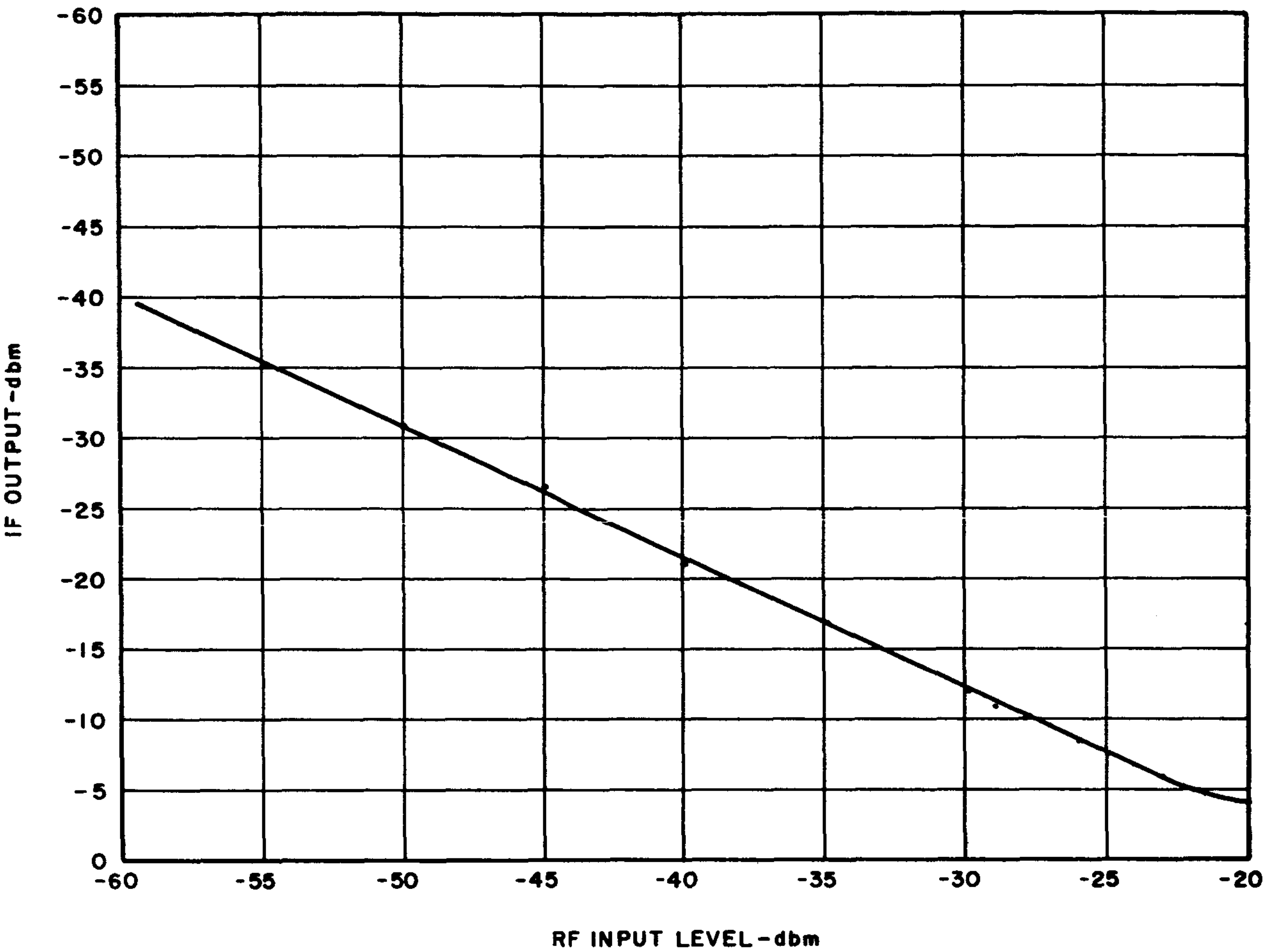


Figure 10. Mixer Preamplifier Linearity Curve

3.2.2 Frequency Gain and Bandwidth

The mixer accepts signals in the frequency range from 1.0 GHz to 2.0 GHz. The IF amplifier center frequency is tuned to 30 MHz and has a 3 db bandwidth of 7 MHz. The RF-to-IF conversion gain is 18 db.

3.2.3 Noise Figure

The noise figure of the mixer preamplifier was measured to be 7.5 db.

3.2.4 Local Oscillator Rejection

Local oscillator rejection was measured to be 7.0 db minimum at 1680 MHz.

3.3 Image Filter

The image filter is a tunable coaxial cavity bandpass filter. The filter serves the dual purpose of rejecting signals at the image frequency as well as rejecting local oscillator signals that might feed through the signal port of the mixer. The filter in the receiver subsystem is tuned to a center frequency (fo) of 1680 MHz. The insertion loss at this frequency is approximately 1.25 db.

The 1-db relative bandwidth is fo ±5 MHz, and the 3-db relative bandwidth is fo ±10 MHz. The attenuation at fo ±30 MHz (local oscillator frequency) is 11 db minimum, and the attenuation at fo ±40 MHz (image frequencies) is 20 db minimum.

The filter is capable of being tuned to any fo between 1665 MHz to 1695 MHz while maintaining the above attenuation characteristics. Figure 11 is a graph of the filter characteristic when tuned to 1680 MHz.

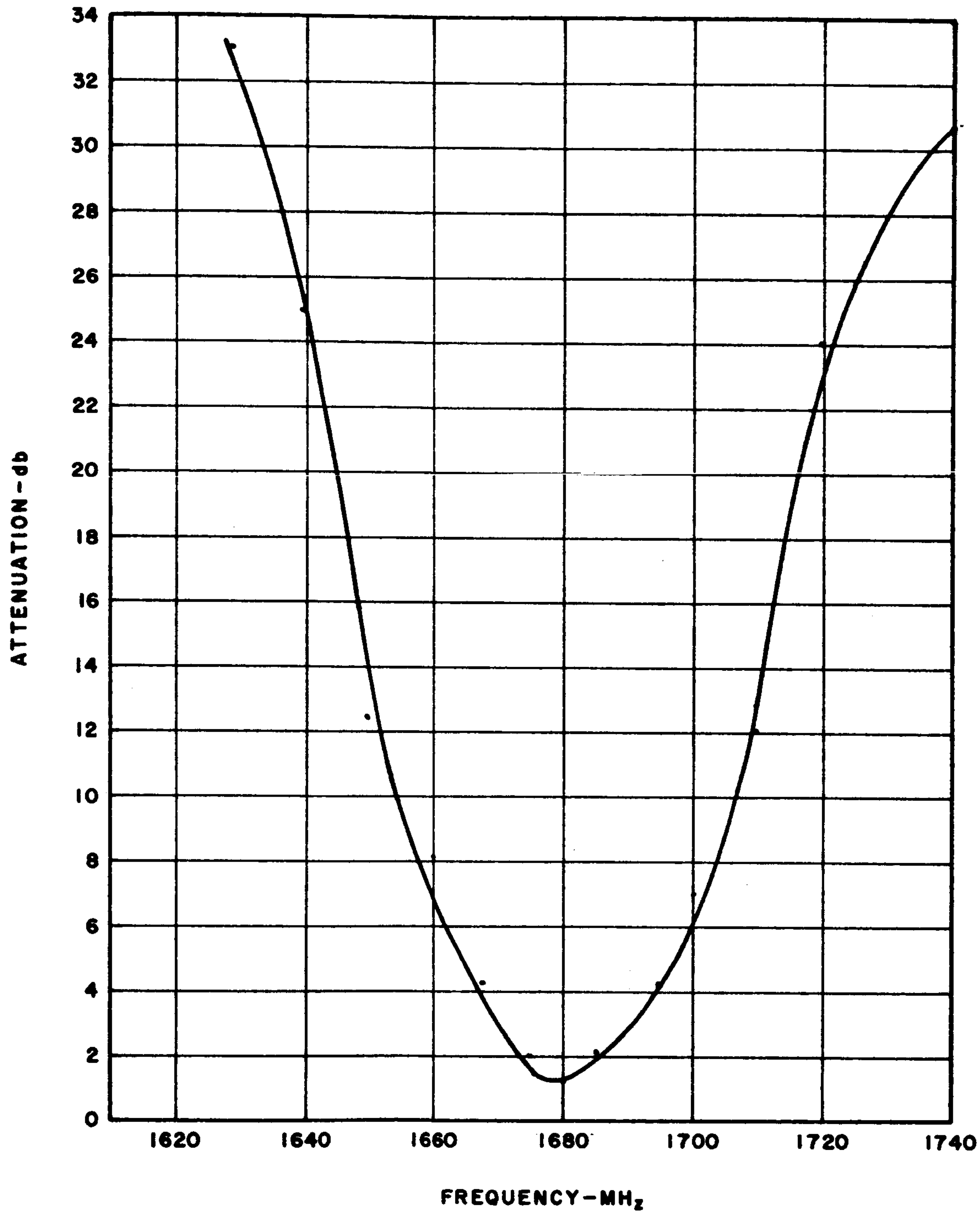


Figure 11. Image Rejection Filter Characteristic Curve

3.4 Bias Power Supply

Incorporated within the receiver subsystem housing is a solid state bias power supply for supplying the dc operating voltages for the tunnel diode amplifier and the mixer preamplifier.

The line voltage (115 vac, 60 Hz) is transformed to 18 volts by transformer T1. This voltage is rectified and filtered for operating the regulator. The transistors Q2 and Q3 make up a Darlington series regulator. Output voltage is controlled by a divider (R7, R8, and R9) supplying a feedback voltage to a G. E. RA-2 reference amplifier, which then controls the voltage available to the series. regulator. The collector of Q4 and base of Q2 are supplied from a constant current from the collector of Q1. Resistor R3 and diode CR6 are connected such that current available from Q1 is limited, thus limiting the output current. The 12-volt output is used to supply the zener diode CR7 which regulates the other output at 6.0 volts. The 6.0-volt output is not used in the present system.

APPENDIX

TEST DATA SHEETS

This Appendix contains the test data sheets for the Tunnel Diode Amplifier and the Mixer Preamplifier.

ELECTRICAL TEST DATA

MODEL NO.: mmP 1-2/5C DATE: 7/28/66

SERIAL NO.: 2-705 DATA TAKEN BY: [illegible]

INPUT FREQUENCY RANGE: 1Gc - 2Gc

IF CENTER FREQUENCY: 30mC

IF BANDWIDTH: 3 DB 8 mc

POWER GAIN (RF TO IF): 18 DB

NOISE FIGURE:

1.8 KMC 7.5 DB

____ KMC ____

____ KMC ____

LO INPUT IMPEDANCE: 50Ω

SIGNAL INPUT IMPEDANCE: 50Ω

IF OUTPUT IMPEDANCE: 50Ω

POWER DRAIN: +12 VDC at 14 ma

(MP1)

THE MICRO STATE ELECTRONICS CORPORATION

A SUBSIDIARY OF RAYTHEON COMPANY

152 Floral Avenue

Murray Hill, New Jersey

TEST DATA SHEET
TUNNEL DIODE AMPLIFIER

MODEL NO. NC 1607

SERIAL NO. 1

F.O. NO. 6840

CUSTOMER BROWN ENG.

P.O. NO. 103678

Frequency	1650 mc	1680 mc	1710 mc
Gain	17.2 db	17.0 db	17.5 db
Noise Figure	4.5 db	4.5 db	4.4 db
Bandwidth at -3 db			170 mc
Saturation Level at ____ db Deviation from Linearity			-39 dbm
Diode Biase Voltage at 75 °F			136 mv

TESTED BY J. LUBENAU

APPROVED BY

Q.A. APPROVED

DATE 7-2-66